

## 5. Methodologies Used to Compile and Estimate Emissions

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This chapter outlines the methodological approach used to compile and estimate emissions and projections. It describes the overall approach and then discusses, by source, any caveats or deviations from this approach. For many countries, the emissions estimates in this report are those reported in National Communications to the UNFCCC or other publicly available documents. This report does not describe the methodologies used to generate these publicly available numbers, but in almost all cases they are consistent with the *Revised 1996 IPCC Guidelines*.

### 5.1 Estimation and Projection Approaches

The general approach was to use country-prepared, publicly available reports wherever possible, with preference given to the most recent report. All estimates were assessed for compatibility with the *Revised 1996 IPCC Guidelines* and to ensure the projections were business-as-usual (BAU). In some cases, EPA made adjustments to the data as emission and particularly projection data were not available from any published sources. An overview of the basic methodology for estimating emissions of methane, nitrous oxide, and high global warming potential (GWP) gases is presented below.

#### 5.1.1 Methane and Nitrous Oxide Emissions

For some countries, EPA used estimates provided in country-specific reports that had more updated information than the information provided in the country's most recent National Communications. The methodology for estimating historical and projected emissions for these countries is presented below.

- **Member States of the European Union (except the United Kingdom):** For historical emissions, the EU-15 submitted a compilation inventory that included all member states for the historical period of 1990 to 1998 (EC, 2000). For projections, three European Commission (EC) reports provide emissions and projections for all the countries (AEA Technology Environment, 2001a, b, c). For a few smaller sources, the

Second National Communication projections were used. The historical estimates for 1990-98 in the three EC projection reports are older than the most recent historical estimates in the compilation report. Therefore, to ensure consistency, EPA based projected emissions on the historical estimates in the compilation report and the projected growth rates as determined in the three EC reports (i.e., EPA applied the projected growth rates to the historical estimates).

- **United Kingdom:** For historical and projected emissions, the UK published a country-specific study in 2000 of non-CO<sub>2</sub> greenhouse gases for most sources (WS Atkins Environment, 2000). For a few smaller sources not included in that report (wastewater, other agricultural and other non-agricultural) the Second National Communication estimates were used.
- **United States:** For historical and projected emissions, the U.S. baseline emissions estimates for each source reflect the methodologies and data reported for the most recent inventory and projections estimate (EPA 2001a and EPA 2001b draft).
- **Newly Independent States:** For Russia and the Ukraine, detailed country study reports were used for historical and projected emissions for most sources. For a few smaller sources not included in that report (i.e., other non-agricultural) the projections were assumed zero or estimated by EPA, as detailed later in the chapter.

For other countries, EPA primarily used the data provided in the countries National Communications to the UNFCCC because they represent each country's own analysis of its detailed national circumstances. However, in some cases, EPA made adjustments to the estimates. These adjustments and the relevant countries are described below for methane and nitrous oxide.

- **Methane and Industrial Nitrous Oxide:** For the remaining countries, the Second National Communication of each country was the preferred source of emissions data. If “business as usual” (BAU) emission projections were available through 2010, they were used in this report. In a small number of cases, the only available projections included control measures. The methodology that EPA used to exclude the impacts of control measures is described in Section 5.2. If the Second National Communication was not submitted or was incomplete, the First National Communication was consulted, which typically contains projections only to 2000. After assessing the estimates from the National Communications, EPA determined if a more recent inventory was submitted to the UNFCCC. If more recent estimates for a country were available for 1990 and/or 1995, these historical estimates were included and the projections were scaled to reflect the change. At the time of publication, Croatia and Liechtenstein had not yet submitted National Communications. The estimates used for Croatia were reported using the Corinair approach.<sup>1</sup> A 1995 UN-submitted report provided estimates for Liechtenstein. The approach used for each of country is documented in Appendix E.
- **Nitrous Oxide from Agriculture and Fossil Fuel Combustion:** While most countries reported historical and projected emissions of agricultural nitrous oxide (N<sub>2</sub>O) in their Second National Communications, those estimates typically did not reflect the significantly improved methodologies

in the *Revised 1996 IPCC Guidelines*. This approach was particularly apparent for the nitrous oxide emissions from agricultural soils. As discussed above, updated N<sub>2</sub>O emission projections were available for the EU-15 and the U.S. Nitrous oxide estimates for the remaining countries were derived as follows:

- **For Australia, Bulgaria, Canada, Hungary, Japan, Monaco, New Zealand, Norway, Slovakia, and Switzerland,** the historical estimates were recent and assumed to be consistent with the *Revised 1996 IPCC Guidelines*. EPA scaled these historical to develop projections. For details see Appendix G.
- **For the Czech Republic, Estonia, Iceland, Latvia, Lithuania, Poland, Romania, Russia, Slovenia, and Ukraine,** EPA estimated nitrous oxide emissions and projections using the most recent methodological guidelines, internationally recognized data sets, and IPCC emission factors. These methodologies are described in detail in each source section.

## 5.1.2 High Global Warming Potential (High GWP) Gas Emissions

For most countries, emissions and projections were not available for these sources. Therefore, high GWP emissions and projections were estimated using detailed source methodologies described later in this chapter.

## 5.2 Adjustments to Methane Estimates

To ensure consistency and completeness, some of the methane data in this report have been estimated by EPA, or modified from publicly available reports. For example, in some cases, countries reported projections that include the anticipated effects of climate change mitigation efforts. Since the purpose of this report is to provide historical and projected emissions in the

absence of climate measures, the anticipated effects of these policies have been added back into the estimates. In other cases, emissions data for certain years were missing and had to be estimated. Some countries presented aggregated projections (e.g., livestock), which had to be disaggregated into their constituents (e.g., enteric fermentation and manure management).

### 5.2.1 Landfilling of Solid Waste

For those countries that included control measures in projections, EPA adjusted the projections to exclude the impacts of the control measures. For those countries with no reported projections, EPA developed estimates. The approach that EPA used for these countries is presented below.

- **Japan, New Zealand, and Switzerland:** These countries included control measures such as methane recovery and waste reduction in their projections. The implementation of mitigation activities for these countries is assumed to result in emissions reductions from the baseline that are similar to those expected to occur in the U.S. from 1990-2010 (30 percent, 61 percent, and 62 percent, respectively, EPA, 1999). To estimate BAU emissions, these anticipated emission reductions associated were added back in to the projections.
- **Russia and European countries without projections:** EPA assumed that future emissions remain constant. In Russia and Eastern Europe this reflects reduced economic activity along with increased use of landfilling.

Exhibit B-2 presents emissions and projections for each country.

### 5.2.2 Coal Mining Activities

Most of the countries that did not report emissions from coal mining do not produce coal domestically, according to the International Energy Outlook (IEA, 1997a). For these countries, EPA assumed methane emissions from coal mining to be zero.

For a few countries, coal-specific reports were available and more recent than other sources. In other countries, no projections were available. The approach used in both cases is outlined below.

- **Russia:** The estimates came from a draft EPA report (EPA, 1999c draft) that focused exclusively on historical and future coal mining methane emissions in Russia. For the majority of underground mines, the methodology was consistent with the IPCC Tier 3 methodology, using measurement data collected by the individual mines. For the remaining underground mines and for surface and post mining, the IPCC Tier 2 methodology was used. To determine the projections, the total projected coal production for a particular year was multiplied by the share of coal production in the region for that year, and then multiplied by the average 1990-1998 emission factor for the specific region. The Russian estimates are the total of these regional estimates.
- **Ukraine:** A Ukrainian coal inventory study provided historical estimates (PEER, 2001 draft). For 2000 to 2010, EPA assumed coal production and, thus related emissions, to decrease by 20 percent, based on a Ukrainian government decision to close 82 of the country's 236 mines by 1999 (EIA, 1997). Economic and social factors are likely to delay completion of these closures until 2005. By 2010, the changes should be implemented and emissions were assumed to stabilize.
- **Poland:** The National Communication reported that emissions are expected to decline sharply by 2010, largely due to anticipated closings of a large number of privatized mines. The pace of mine closures might be slower than anticipated, however, because of social and economic considerations. Unlike Germany and the UK, which are expecting drastic reductions in coal production, the Polish economy is largely coal-based (97 percent of energy consumption, IEA,

1997a), with negligible natural gas and oil reserves. Also, Poland will continue to sell some coal to foreign markets to earn foreign currency. Many of Poland's gassiest mines are located near major industries, where there is increased possibility for methane recovery and use. With the expected closure of highly gassy longwall mines and modest increases in methane recovery and use, EPA assumed emissions will decline 5 percent over each 5-year period to 2010.

In those cases in which a projection of future emissions was not available, EPA used the following two types of assumptions: (1) for Eastern European countries, EPA used Ukraine and Germany as analogue countries (countries with similar circumstances or geography); and (2) for Western European countries, EPA assumed that emissions would remain constant.

Appendix E provides specific information on particular countries. Exhibit B-3 presents emissions estimates and projections data for coal mining.

### 5.2.3 Natural Gas and Oil Systems

In some cases, no projections were available. For these countries, EPA used one of two approaches: (1) for Eastern European countries, EPA assumed emissions remain constant; this assumption balances increased oil and gas production and use with modernization of the system; or (2) for Western European countries, EPA projected historical inventories based on trends in analogue countries.

Appendix E provides specific information on particular countries. Exhibit B-4 presents emissions estimates and projections data for natural gas and oil systems.

### 5.2.4 Livestock Manure Management and Enteric Fermentation

For some countries the emissions associated with livestock manure management and enteric fermentation were reported as combined estimates.

EPA disaggregated these emissions for several countries as indicated below.

- **Australia, the Czech Republic, Estonia, Lithuania, New Zealand, Norway, and Switzerland:** EPA disaggregated the projections based on the relative share of each provided in disaggregated historical estimates for each country.
- **Ukraine:** EPA disaggregated the total reported in the mitigation study (Raptoun, et al., 1996) according to the patterns seen in Poland and Estonia.

For some countries, no projections were available. For these countries, EPA used one of two approaches: (1) for Eastern European countries, EPA assumed they would experience a short-term decline in emissions (to 2000) followed by an increase; this trend is consistent with economic projections, as well as the countries for which projections were available (e.g., Ukraine); or (2) for Western European countries, EPA assumed that emissions would remain constant.

Exhibits B-5 and B-6 present emissions estimates and projections data for each country.

### 5.2.5 Wastewater Treatment

Emissions from this source are typically small, and some countries did not report this category in their inventories. In cases where a suitable analogue country was available, EPA scaled emissions on the basis of the per capita emissions rate of the analogue country. In cases where no projections were available, EPA assumed that emissions would remain constant over time. Where wastewater projections were combined with landfill emissions, EPA disaggregated estimates based on the percentages for each source taken from the latest inventory.

Exhibit B-7 presents emissions estimates and projections data for each country.

## 5.2.6 Other Agriculture Sources

Less than half of the developed countries included categories such as rice cultivation and agricultural residue burning in their inventories. Australia and Japan report the only significant emissions. For countries with historical estimates but no projections, EPA assumed future emissions to be constant.

Exhibit B-8 presents emissions estimates and projections data for each country.

## 5.2.7 Other Non-Agricultural Sources

This category includes emissions sources such as fuel combustion, industrial processes, and waste incineration, which are usually small. Some of the inventory estimates may be incomplete, indicating that the values are not fully comparable. In those cases in which a projection of future emissions was not available, EPA assumed future emissions to remain constant.

Exhibit B-9 presents emissions estimates and projections data for each country.

## 5.3 Methodology and Adjustments to Approaches Used for Nitrous Oxide

To maintain a consistent set of emissions estimates and projections, EPA made adjustments to publicly available N<sub>2</sub>O data, and in some cases generated new estimates. This step was necessary particularly for N<sub>2</sub>O emissions from agricultural soils and mobile combustion. Unlike the major sources of methane, these sources were significantly revised in the *Revised 1996 IPCC Guidelines*. Many countries were not able to apply the more rigorous methods in time for the Second National Communication. The following sections summarize the methodologies by source, including any adjustments.

### 5.3.1 Nitrous Oxide Emissions from Agricultural Soils

Given the lack of available country-developed information for this source, EPA developed methods

of estimating both emissions and projections. For the Czech Republic, Estonia, Iceland, Latvia, Lithuania, Poland, Romania, Russia, Slovenia, and Ukraine, EPA developed both emissions and projections. For Australia, Bulgaria, Canada, Hungary, Japan, Monaco, New Zealand, Norway, Slovakia, and Switzerland, the recent historical estimates are available and appear to incorporate the Revised 1996 IPCC Guidelines. EPA developed projections following the method described below, but scaled them to the inventory data.

EPA used the bottom-up approach outlined in the *Revised 1996 IPCC Guidelines* (IPCC, 1997), which made significant methodological improvements in both coverage and emission factors. The methodology outlines three major components: (1) direct emissions from agricultural soils, (2) direct emissions from deposition of animal waste, and (3) indirect emissions. Direct emissions are broken down further into sub-categories including fertilizer application, histosol cultivation, cultivation of nitrogen fixing crops, incorporation of crop residues, and daily spread operations. Histosol cultivation area, alfalfa production, and consumption of commercial organic fertilizers were not available and thus are not included in this report.

The *Revised 1996 IPCC Guidelines* provide default emission factors for different world regions, but require country-specific activity data. The specific approach and data sources used to estimate historical and projected emissions from each sub-component in this source category are presented in Appendix G.

Exhibit C-2 presents total N<sub>2</sub>O emission estimates from agricultural soil management for each developed country.

### 5.3.2 Nitrous Oxide Emissions from Industrial Processes

Most countries report N<sub>2</sub>O emissions from industrial processes in their Second National Communication or other reports. For the few countries with no estimates for this source, emissions for these countries are not reported.

**Exhibit 5-1: Fuel Types Included in N<sub>2</sub>O Emissions from Fossil Fuel Combustion Analysis**

Coal	Natural Gas	Oil
Hard Coal	Natural Gas	Crude
Brown Coal	Refinery Gas in metric tons	Motor Gasoline
Coke Oven Coke	Ethane	Aviation Gasoline
Gas Coke	Liquefied Petroleum Gases	Gasoline - type Jet Fuel
Peat	Gas Works Gas	Kerosene - type Jet Fuel
BKB	Coke Oven Gas	Kerosene
	Blast Furnace Gas	Gas/Diesel Oil
	Oxygen Steel Furnace Gas	Residual Fuel Oil
		Petroleum Coke
		Non-specified Petroleum Products
		Naphtha
		Patent Fuel

Total nitrous oxide emissions from industrial sources are summarized in Exhibit C-3. The data sources for each country can be found in Appendix F.

### 5.3.3 Nitrous Oxide Emissions from Stationary Fossil Fuel Combustion

Many countries do not report N<sub>2</sub>O emissions from fossil fuel combustion. EPA developed methods of estimating both emissions and projections. For the Czech Republic, Estonia, Iceland, Latvia, Lithuania, Poland, Romania, Russia, Slovenia, and Ukraine, EPA developed both emissions and projections. For Australia, Bulgaria, Canada, Hungary, Japan, Monaco, New Zealand, Norway, Slovakia, and Switzerland, the recent historical estimates are available and appear to incorporate the *Revised 1996 IPCC Guidelines*. EPA developed projections following the method described below, but scaled them to the inventory data.

#### **Historical Emissions**

EPA collected fossil fuel consumption data by country, fuel product and sector use for all major fuel types as indicated in Exhibit 5-1 (IEA, 1997b). The sectors included in the analysis were the electric utility industry and the manufacturing and construction industries. The consumption was then

multiplied by the IPCC Tier 1 N<sub>2</sub>O emissions factor for each fuel type and sector. EPA estimated historical data for two countries with no reported historical estimates:

- For Monaco, French data on per capita energy demand was applied to Monaco to estimate fuel consumption by fuel type for each sector (IEA, 1997b).
- For Liechtenstein, EPA applied the average per capita energy demand from Austria and Switzerland to the population of Liechtenstein (IEA, 1997b).

#### **Projected Emissions**

EPA applied region specific average annual growth rates by fuel type (IEA, 1997b) to 1995 consumption data to determine future energy consumption for 2000, 2005, and 2010. The growth factors were only available for industrialized, developing and EE/FSU country categories (IEA, 1997b), as summarized in Exhibit 5-2. The EE/FSU rates were applied to Russia and Eastern Europe and industrialized rates were applied to all other countries. For each country, the projected energy consumption by fuel product and sector use were multiplied by the IPCC Tier 1 emission factors.

**Exhibit 5-2: Annual Growth Rates for Electric Utilities and Manufacturing/Construction Sectors (%/year)**

Energy Source	Industrialized Countries	Developing and EE/FSU Countries
Oil	1.1	3.3
Natural Gas	2.6	3.8
Coal	0.7	2.5
Biomass/Waste	1.3	3.1

*Note: EE/FSU rates are applied to Russia and Eastern Europe and Industrialized rates are applied to all other Developed Countries in the analysis. Source: IEA (1997b).*

### 5.3.4 Nitrous Oxides Emissions from Mobile Fossil Fuel Combustion

For many developed countries, the estimates provided in the Second National Communications did not reflect the updated emission factors provided by the *Revised 1996 IPCC Guidelines*. These new emission factors incorporated the results of measurement projects, and lead to a significant revision upwards of N<sub>2</sub>O emissions. To ensure consistency across sources, and provide more complete estimates for all countries, EPA recalculated emissions for all countries using the updated emission factors.

The basic approach was to estimate fuel consumption for each country, assign the fuel consumption to different classes or categories of vehicles, and then apply the updated emission factors at a disaggregated level. The details are summarized in Appendix H.

Emissions from all modes were summarized and are presented in Exhibit C-7.

### 5.3.5 Nitrous Oxide Emissions from Manure Management

This section addresses emissions and projections of N<sub>2</sub>O resulting from the storage or handling of livestock manure (i.e., before the manure is added to soils). N<sub>2</sub>O emission levels from manure management systems depend on the type of system and the length of time the waste stored. Similar to agricultural soils, the manure methodology was revised in the *Revised 1996 IPCC Guidelines* and

many countries were not able to apply the more rigorous methodologies in time for the Second National Communication.

Given the lack of available country-developed information for this source, EPA developed methods of estimating both emissions and projections. For the Czech Republic, Estonia, Iceland, Latvia, Lithuania, Poland, Romania, Russia, Slovenia, and Ukraine, EPA developed both emissions and projections. For Australia, Bulgaria, Canada, Hungary, Japan, Monaco, New Zealand, Norway, Slovakia, and Switzerland, the recent historical estimates are available and appear to incorporate the *Revised 1996 IPCC Guidelines*. EPA developed projections following the method described below, but scaled them to the inventory data.

#### **Historical Activity Data**

FAO reported historical animal population data for most countries (FAO, 1998c). The exceptions are described below:

- Luxembourg: EPA used N<sub>2</sub>O emissions from agricultural soils, as reported in each country's National Communication, as a proxy (98% Belgium and 2% Luxembourg).
- Croatia, Estonia, Latvia, Lithuania, Russia, and Ukraine: Data for 1990 are reported for the Former Soviet Union. EPA divided the 1990 livestock populations in the Former Soviet Union among Estonia, Lithuania, Russia, and Ukraine based upon each country's relative share in 1995. The 1995 data filled the gap for 1990 for Croatia.
- Czech Republic and Slovakia: In 1990, population statistics were reported for Czechoslovakia. Each country's 1995 population statistics were used to determine relative shares.
- Liechtenstein: No data were available.

#### **Historical Emissions**

EPA estimated total livestock nitrogen excretion based on default values for each animal type. The

total nitrogen excretion was then divided among animal waste management systems using IPCC default assumptions. To estimate N<sub>2</sub>O emissions, the excreted livestock nitrogen for each management system (with the exception of pasture, range and paddock, and daily spread) was multiplied by IPCC default emission factors specific to the animal waste management system.

### ***Projected Emissions***

Animal population forecasts were not available for 2000, 2005 and 2010 except for the U.S. To project other countries' emissions, EPA assumed emissions would grow at the same rate as methane emissions from livestock manure.

Direct N<sub>2</sub>O emissions from deposition of animal waste are summarized in Exhibit C-8.

## **5.4 Estimation and Projection Approaches Used for High Global Warming Potential Gases**

High global warming potential (High GWP) gas emissions result from the use of substitutes for ozone-depleting substances (ODSs) and from other industrial sectors. Until recently, few nations have made significant efforts to track and project use and emissions of HFCs, PFCs, and SF<sub>6</sub>. If countries did present information on these gases it was often partial estimates or an aggregate estimate. In either their National Communication or more recent literature, Austria, Canada, Germany, Japan, Norway, Russia, the United Kingdom, and the United States provide enough information to incorporate in this analysis.

### **5.4.1 HFC and PFC Emissions from the Use of Substitutes for ODS Substances**

This analysis incorporates estimates of the emissions of ODS substitutes available through the National Communications of Japan, Norway, Russia, the United Kingdom, and the U.S.<sup>2</sup> EPA assumed that the U.S. transition pattern from ODS to alternatives

can be applied to the remaining countries. Additionally, this analysis uses a U.S. emission profile for each end use application.

The U.S. transition pattern was customized to each region or country using adjustment factors that take into consideration differences in the rates of the phase out and the distribution of ODS consumption across end uses.

### ***The Vintaging Model***

EPA uses a "Vintaging Model" of ODS-containing equipment and products to estimate the use and emissions of ODS substitutes in the U.S. (This model is discussed in more detail in Appendix I.) The model tracks the use and emissions of each of the substances separately for each of the ages or "vintages" of equipment.

The consumption of ODS and ODS substitutes are modeled by estimating the amount of equipment or products sold, serviced, and retired each year, and the amount of the chemical required to manufacture and/or maintain the equipment and products over time. Emissions are estimated by applying annual leak rates and release profiles to each population of equipment or product. By aggregating the data for more than 40 different end-uses, the model estimates and projects annual use and emissions of each compound over time. For this analysis, the model calculates a "business as usual" case that does not incorporate measures to reduce or eliminate the emissions of these gases other than those regulated by U.S. law.

The major end-use categories defined in the Vintaging Model to characterize ODS use in the U.S. are: refrigeration and air conditioning, aerosols, solvent cleaning, fire extinguishing equipment, foam production, and sterilization. The Vintaging Model estimates the use and emissions of ODS alternatives by taking the following steps:

1. Collection of historical emissions data from published sources and industry experts.



2. Simulation of the implementation of control technologies: The Vintaging Model uses detailed characterizations of the existing uses of the ODSs, as well as data on how the substitutes can replace the ODSs, to simulate the implementation of control technologies that ensure compliance with ODS phase out policies. As part of this simulation, the ODS substitutes are introduced in each of the end uses over time as needed to comply with the ODS phase out.
3. Estimation of emissions of the ODS substitutes: The chemical use is estimated from the amount of the substitutes that are required each year for the manufacture, installation, use, or servicing of products. The emissions are estimated from the emission profile for each vintage of equipment or product in each end use.

### ***Applying the Vintaging Model to Other Developed Countries***

To apply the Vintaging Model to other countries, EPA used the following methodology:

**Historical ODS activity data:** UNEP provided estimates of 1990 ODS consumption by country. The estimates for the European Economic Community (EEC) were provided in aggregate and GDP was used as a proxy to divide the consumption of the individual member nations from the EEC total.<sup>3</sup> The UNEP report provided consumption data in terms of ozone depletion potential (ODP) weighted totals for the major types of ozone depleting substances: CFCs, HCFCs, halons, carbon tetrachloride, and methyl chloroform. To obtain unweighted ODS consumption values, EPA followed the methodology outlined below:

- CFCs: EPA applied the U.S. pattern of CFC consumption for each individual CFC compound to the aggregate ODP-weighted totals for each country. As a check, the proportions of CFCs produced globally in 1990 were also used to estimate the unweighted total of CFCs from the ODP-weighted totals (AFEAS, 1997). The total

unweighted CFC consumption calculated with the U.S. and AFEAS proportions differed by less than 1 percent.

- HCFCs: EPA applied the U.S. average ODP for 1989 HCFC consumption, which was 0.056.
- Methyl chloroform and carbon tetrachloride: EPA used a straight conversion from ODP-weighted totals to unweighted totals.
- Halons: Three different halons (Halon 1211, Halon 1301, and Halon 2402) comprised the ODP-weighted halons totals in the UNEP estimates. EPA assumed that all of the countries use both Halon 1211 and Halon 1301 but only the Former Soviet Union countries use Halon 2402. The ODP-weighted values were separated into unweighted totals of Halon 1211 and Halon 1301 using ratios of 1211 production to 1301 production in 1990 (UNEP, 1998). For the Former Soviet Union, the total was separated into all three halons based upon the 1990 consumption reported for the Russian Federation (Russia MPENR, 1994).

**Apportionment of historical ODS consumption to end-use sectors:** Data on the end-use distributions of ozone depleting substances in 1990 were available for the United States, the United Kingdom, and the Russian Federation, as shown in Exhibit 5-3. The 1990 end-use sector distribution for the United States was used for Canada. The United Kingdom's distribution was applied to the EU-15, Australia and New Zealand. The Russian Federation's distribution was applied to the Former Soviet Union countries and the non-EU-15 European countries.

**ODS substitute emissions:** EPA assumed for this report that all countries will transition from ODS to ODS substitutes in the same way as the United States, with adjustments in later steps to account for regional differences. Using the U.S. data, EPA developed a relationship between the 1990 ODS consumption and ODS substitute emissions using two ratios: (1) the U.S. ratio of unweighted base year

**Exhibit 5-3: End-Use Sector Distribution of 1990 Unweighted ODS Consumption (%)**

	CFCs						HCFCs <sup>a</sup>		
	Refrigerant	MDI Aerosols <sup>b</sup>	Non-MDI Aerosols	Solvents	Foams	Sterilization	Refrigerant	Aerosols	Foams
<b>United States</b>	21.2%	1.8%	0.0%	41.1%	16.2%	19.8%	100%	0.0%	0.0%
<b>Russia</b>	16.7%	0.9%	53.7%	21.1%	7.5%	0.0%	80%	10.0%	10.0%
<b>United Kingdom</b>	21.3%	1.5%	27.6%	26.7%	21.5%	1.4%	69%	5.1%	25.9%

<sup>a</sup> The breakout of HCFCs in Russia is an estimate based on the fact that Russia had CFC use in refrigeration, aerosols, and foams, and that in both the U.S. and U.K., HCFC use was more heavily weighted toward refrigeration than the other end-use sectors

<sup>b</sup> The pharmaceutical use of aerosols in Russia in 1990 is taken directly from Table 3.4.b of *Phaseout of Ozone Depleting Substances in Russia*. EPA estimated the MDI use in United Kingdom to be 5 percent of the total 1990 CFC aerosol use. Though MDIs are expected to account for the majority of HFC use in aerosols, limited HFC aerosol uses in other specialized applications are likely to include such products as office equipment dusters.

Sources: U.S. end-use sector breakouts are calculated from results of EPA's Vintaging Model.

Russia's end-use sector breakouts are taken from MPNER (1994), pp. x-xi, 27-28.

U.K. end-use sector breakouts are from UK DEP (1996), pp. 4.4,4.6.

(1990) ODS consumption to unweighted substitute consumption in a given year, for each of the twelve end-use sectors; and (2) the U.S. ratio of unweighted U.S. ODS substitute consumption in a given year to GWP-weighted U.S. ODS substitute emissions in the same year. The two ratios, when multiplied together, form a ratio of unweighted 1990 U.S. ODS consumption (metric tons) to weighted U.S. ODS substitute emissions (MMTCO<sub>2</sub>) in a given year. However, these two ratios are valid only if they result in real, non-zero numbers, therefore, the U.S. substitute emissions and the 1990 U.S. ODS consumption values must both be non-zero. This criteria was not met in two instances and adjustments were made:

- **Non-medical dose inhaler (Non-MDI) aerosols:** The U.S. phased out non-MDI use of CFCs in aerosols prior to 1990, therefore, the 1990 consumption was zero. In order to determine a non-zero ratio for this step, the unweighted U.S. consumption of non-MDI ODS substitutes (including a large market segment that transitioned into non-GWP, non-ODP substances) was used as a proxy for U.S. 1990 non-MDI ODS consumption, for this step only. This assumption is valid if the market size of U.S. non-MDI aerosols was not affected by the

transition from ODS to ODS substitutes. The result is that this analysis assumes that the transition of non-MDI aerosols out of ODS was completed by 1995 for both Russia and the United Kingdom, where CFC usage in non-MDI aerosols is significant.

- **HCFCs in foam blowing and non-MDI aerosols:** In 1990, the U.S. was not using HCFCs in foam blowing or in non-MDI aerosols, leading to a zero value for HCFC consumption. For the purposes of developing these ratios, EPA assumed that the ODS substitutes for HCFCs in these two markets would follow the same transition scenarios as U.S. CFC-blown foams and non-MDI aerosols, respectively.

The country-specific unweighted 1990 consumption of ODS is divided by the ratio of unweighted 1990 ODS consumption to GWP-weighted substitute emissions, as described above. This calculation is performed for each of the twelve end-use sectors for each country for each year.

**Transition adjustment factors:** To account for country differences in the transition from ODS to ODS substitutes, EPA adjusted other countries' emissions estimates based upon qualitative information about how their substitution will likely

**Exhibit 5-4: Adjustment Factors Applied to ODS Emissions for Each Country**

Country	CFCs					HCFCs			Halons Fire Extingu- ishing	CT Solvent	MCF Solvent
	Refrig- erant	Aerosol	Solvent	Foams	Steril- ization	Refrig- erant	Aerosol	Foams			
Australia and New Zealand	0.90	1.00	1.00	0.50	1.00	0.90	1.00	0.50	1.00	1.00	1.00
Canada	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FSU	0.75	1.00	0.50	0.20	0.50	0.75	1.00	0.20	1.00	0.50	0.50
EU-15	0.80	1.00	0.80	0.40	0.90	0.80	1.00	0.40	1.00	0.80	0.80
Europe (non-EU-15)	0.75	1.00	0.50	0.20	0.50	0.75	1.00	0.20	1.00	0.50	0.50
Japan	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

differ from that of the US. Each country's emissions were multiplied by an adjustment factor, which is between 0 and 1.0. In other words, the U.S. substitution in each end-use sector was assumed to be a maximum. For example, an adjustment factor of less than one was applied to end-uses such as refrigerants in Europe, because EPA is aware that European appliances are more likely to use hydrocarbon refrigerants in place of HFCs. Overseas foam use is also adjusted downward in some cases because of the use of cyclopentane in lieu of HFCs. Exhibit 5-4 presents the adjustment factors that were applied for each country or group of countries.

**Timing factors:** In addition to the adjustment factors for each end-use sector, a timing adjustment was applied for the Former Soviet Union countries (FSU) and non-EU-15 European countries. Since these nations will transition to substitutes more slowly, EPA multiplied the emission estimates by a timing factor to reflect the anticipated delay in their transition. Exhibit 5-5 shows the timing factors applied to the emissions in each year.

**Exhibit 5-5: Timing Factors Applied to ODS Emissions Estimates**

Country/ Country Group	1990	1995	2000	2005	2010
FSU	0	0	0.25	0.5	0.75
Europe (non-EU-15)	0	0	0.25	0.5	0.75

**Adjustment factor for refrigerant recycling:** A third adjustment was required to account for

increased emissions, compared to the U.S., which may result from a lack of recycling or recovery of refrigerants in non-EU-15 European countries and the FSU. Exhibit 5-6 presents these adjustment factors.

**Exhibit 5-6: Recycling Adjustment Applied to Refrigeration Emissions Estimates**

Country/Country Group	Adjustment
Australia and New Zealand	1.0
Canada	1.0
FSU	1.1
EU-15	1.0
Europe (non-EU-15)	1.1
Japan	1.0

### 5.4.2 HFC-23 Emissions as a Byproduct of HCFC-22 Production

For Norway, Japan, the U.K., and the U.S., emissions estimates are available and taken directly from national reports (Norway MOE, 1997; METI, 2001; WS Atkins Environment, 2000; and EPA, 2001a, c).

#### **Historical HFC-23 Emissions**

For developed countries without estimates, consumption and production data of HCFC-22 were available for 1989 and all years from 1992 to 1998, as reported to the Secretariat by the Parties to the Montreal Protocol (UNEP, 1999). The reported production and consumption is expressed in ozone depletion potential (ODP) weighted units and was aggregated with all HCFCs.<sup>4</sup> EPA developed estimates for 1990 by linearly interpolating between 1989 and 1992. The Alternative Fluorocarbon

Environmental Acceptability Study (AFEAS, 1999) was used to compare 1990 HCFC-22 production estimates with UNEP production data by country. In addition, EPA made the following assumptions:

1. As the consumption estimates from UNEP do not include HCFC-22 produced for use as feedstock, EPA adjusted reported estimates to include an additional 35 percent of HCFC-22 production (AFEAS, 1999).<sup>5</sup>
2. The 1995 and 1998 HCFC consumption numbers from UNEP included more than HCFC-22. The AFEAS study used sales of HCFC-22, HCFC-142b, and HCFC-141b to determine the proportion of HCFC-22 within total HCFC sales. This proportion by region was then applied to HCFC consumption reported under UNEP. Again, the estimates were adjusted for 35 percent to account for feedstock.

### **HFC-23 Projected Emissions**

EPA used 1998 HFC-23 emissions as a baseline to project emissions into the future. The method for projecting the baseline data was as follows:

- End-use breakdown of HCFC-22 for 1998. EPA assumed that 65 percent of current global HCFC-22 production is used to produce refrigeration, air-conditioning, and foam products. The other 35 percent of HCFC-22 production was assumed to be used as feedstock material, which is not controlled by the Montreal Protocol. Manufacturers have the incentive to increase production for feedstock material use to keep plants producing at capacity.
- Growth rate for feedstock and other uses: EPA assumed that production of HCFC-22 for feedstock materials would grow at a 1.5 percent annual rate in each country. The rate of growth for production of HCFC-22 for regulated end-uses (i.e., for refrigeration) was determined by linearly decreasing production so that complete

phase-out occurred based on the phase-out schedule for each country.

- Emissions for each country through 2010: Since production and HFC-23 emissions are directly linked, emissions related to non-feedstock uses were decreased at the phase-out rate while the emissions related to feedstock use were increased at the 1.5 percent annual rate, for each country.

The resulting emissions estimates are presented in Exhibit D-3.

### **5.4.3 Perfluorocarbon (PFC) Emissions from Primary Aluminum Production**

The emissions estimates for Austria, Canada, Germany, Norway, Japan, the UK, and the U.S. are taken directly from National Communications or country reports (Radunsky, 2000, Environment Canada 1997, Germany FME 1997, Norway MOE 1997, WS Atkins Environment 2000, and EPA, 2001a, c). The methodologies employed included smelter-specific information and provided estimates and projections with a lower level of uncertainty.

**Exhibit 5-7: 1990 and 1995 HCFC-22 Production in Developed Countries (metric tons)**

Country	1990 HCFC-22 Production	1995 HCFC-22 Production
Australia	2,352	1,259
Canada	3,570	480
France	22,000	47,141
Germany	9,800	5,212
Greece	1,606	3,065
Italy	6,824	3,764
Netherlands	10,479	6,862
Russia	16,091	3,345
Spain	8,267	6,025
UK	12,952	11,123

Source: UNEP (1997), AFEAS

The methodology used to estimate PFC emissions from aluminum production for the remaining countries was as follows.

### ***Historical Primary Aluminum Production by Country***

Primary aluminum production data for developed countries for 1990 and 1995 was taken from the background materials used for the report entitled *Greenhouse Gas Emissions from the Aluminum Industry* (IEA, 2000). EPA adjusted the data for countries in Western Europe, Eastern Europe, and the Former Soviet Union based upon personal communication with Eirik Nordheim from the European Aluminum Association (1999).

### ***Projected Primary Aluminum Production by Country***

This analysis aggregated individual smelter production data to provide regional-level, technology-specific production projections through 2010. Projections are based upon anticipated smelter openings, smelter closings, and changes in aluminum demand, which was modeled using regional Gross Domestic Product estimates. Within each region and technology type, production totals were divided among the respective countries depending upon their historically reported proportion of regional production. Exhibit 5-8 shows aluminum producing countries within each region.

For Western Europe, Eastern Europe, and the Former Soviet Union, the regional production totals could not be used since the historical data were adjusted. Expected smelter opening and closing information was combined with technology-specific growth rates (2.5 percent per year for prebake cells, 0.5 percent per year for Soderberg cells) to forecast future regional production. The regional production was then apportioned according to each country's historical share of regional production within a given technology type, as stated above.

**Exhibit 5-8: Regional Categories for Developed Countries**

Region	Aluminum Producing Developed Countries
Asia	Japan
Australasia	Australia, New Zealand
Eastern Europe and the Former Soviet Union	Croatia, Poland, Romania, Russia, Slovakia, Slovenia, Ukraine
North America	Canada, United States
Western Europe	Austria, France, Germany, Greece, Hungary, Iceland, Italy, Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom

### ***PFC Emission Factors***

The *Aluminum Annual Review 1998* (Anthony Bird Associates 1998) provides the cell technology type for individual smelters within each country; by combining this information with forecasts of regional technology upgrades, emission factors gained both regional and technological sensitivity.

EPA estimated emission factors using the Tier 2 IPCC good practice methodology for calculating PFC emissions from primary aluminum production (IPCC, 2000). This methodology is shown mathematically below:

$$\text{Emission Factor (kg CF}_4 \text{ or C}_2\text{F}_6 \text{ per tonne Al)} = \text{Slope-coefficient} \times \text{AE Minutes/Cell-Day}$$

Where,

$$\text{AE Minutes/Cell-Day} = \text{Anode Effect Frequency} \times \text{Anode Effect Duration}$$

$$\text{Anode Effect Frequency} = \text{Number of Anode Effects per Cell-Day}$$

$$\text{Anode Effect Duration} = \text{Average Anode Effect Duration in Minutes}$$

Since operating parameter (i.e. average anode effect (AE) duration and AE frequency) and slope-coefficient (S-value) information were not available for all smelters, technology-specific regional default values for AE Minutes/Cell-Day (IPAI, 1999) and

technology-specific S-values were used (IPCC, 2000).

The emission factors were projected through 2010 by extending recent trends in AE Minutes/Cell-Day. The future AE Minutes/Cell-Day values differ among the various regions according to estimated technology diffusion rates.

**Exhibit 5-9: 1990 and 1995 AE Minutes/Cell-Day Values By Tech Type**

Technology Type	AE Minutes/Cell-Day	
	1990	1995
Vertical Stud-Soderberg (VSS)	10.3	7.1
Horizontal Stud-Soderberg (HSS)	3.5	3.1
Side Work-Prebake (SWPB)	6.5	5.3
Center Work-Prebake (CWPB)	3.4	1.6
Point Feed-Prebake (PFPB)	2.3	1.1

Source: IPAI, 1999.

### **PFC Emissions**

EPA calculated emissions by multiplying the emission factors by the aluminum production.

A summary of emissions is presented in Exhibit D-4.

### **5.4.4 Sulfur Hexafluoride (SF<sub>6</sub>) Emissions from Magnesium Production**

Austria, Canada, Germany, Japan, Norway, the United Kingdom, and the U.S. included partial or complete SF<sub>6</sub> estimates from magnesium. EPA used these estimates to replace or inform the estimates for those countries (Radunsky, 2000, Environment Canada 1997, Germany FME 1997, Norway MOE 1997, WS Atkins Environment 2000, and EPA, 2001c). For the remaining countries, the following method was used:

#### **Historical Magnesium Production by Country**

The U.S. Geological Survey publishes data for primary production of magnesium by country through 1998 (USGS, 1999). For those countries that produce magnesium, die casting production was estimated by applying the U.S. proportion of primary production to diecasting consumption, shown in

Exhibit 5-10, to each country's primary production for each year. Estimates of magnesium diecasting production for countries with no primary magnesium production (i.e., importers) were taken from their National Communications to the United Nations Framework Convention on Climate Change, information on commerce activities from the USGS (1999), and estimates of magnesium casting activities in car producing countries. These countries include Austria, Germany, Japan, Sweden, and the United Kingdom. Additionally, total die casting production is in agreement with the USGS' estimate that die casting accounts for roughly 30 percent of magnesium consumption globally.

**Exhibit 5-10: Portion of U.S. Primary Magnesium Production Processed by Die Casting Industry (%)**

Year	Percent
1990	6.5%
1991	7.4%
1992	7.5%
1993	9.5%
1994	12.2%
1995	10.7%
1996	12.3%
1997	16.5%
1998	23.9%

### **Historical and Projected Emission Factors**

The emission factor for diecasting (4.1 kg SF<sub>6</sub>/metric ton Mg) was taken from Gjestland and Magers (1996). The primary production emission factor (0.95 kg SF<sub>6</sub>/metric ton Mg) was estimated by dividing the total sales of SF<sub>6</sub> to the magnesium industry by the total magnesium primary production in each country. (Global sales data were voluntarily provided by major chemical manufacturers.) Although the Russian Federation is a major producer of magnesium metal, EPA assumed it did not transition to SF<sub>6</sub> from the older method, which used sulfur dioxide (SO<sub>2</sub>), during the time frame of the analysis. EPA assumed these emission factors remained constant over time.

## ***SF<sub>6</sub> Emissions***

EPA assumed that all the SF<sub>6</sub> used is emitted. Emissions were calculated by multiplying the primary magnesium production data and die-casting production data by the corresponding emission factor for each country for each year.

Exhibit D-5 presents the emissions estimates.

### **5.4.5 Sulfur Hexafluoride (SF<sub>6</sub>) Emissions from Electric Utilities**

Estimates for the UK, Japan and the United States were taken directly from recent country reports (WS Atkins Environment, 2000; METI, 2001; and EPA 2001b, c). These recent estimates were made using country-specific data, and are considered more reliable than the results of the global apportionment outlined below. Several countries report emissions from this sector in their National Communications but these data were not used in the current analysis because the National Communications do not take into consideration recent SF<sub>6</sub> sales information.

The following methodology was used to determine SF<sub>6</sub> emissions from utilities.

#### ***Countries That Use SF<sub>6</sub> in Their Utilities Industry***

This list was determined from conversations with equipment manufacturers and from National Communications.

#### ***Electricity Consumption***

EIA provides country specific electricity consumption, region specific growth rates, and a few country specific growth rates (EIA, 2001). Individual countries have their electricity consumption estimated using the region specific growth rates or, where available, country-specific growth rates. Each country's electricity consumption was normalized as a fraction of the world total.

#### ***Historical and Projected Global SF<sub>6</sub> Emissions***

Historical global emissions of SF<sub>6</sub> from electrical utilities for 1990 to 1999 were estimated from global

sales of SF<sub>6</sub> to electrical utilities (Rand, 2000). Future global emissions are projected assuming a 4.5 percent annual decrease for 1999 through 2002 (Rand, 2000) and a 0.7 percent annual increase for 2002 through 2020. The 0.7 percent growth rate is a combination of (1) a growth rate of 1.7 percent for U.S. electric generating capability between 1999 and 2020 (EIA, 2001) and (2) a growth rate of -1.0 percent per year for the charge of SF<sub>6</sub> contained in a typical piece of electrical equipment of a given voltage capacity (Sauer, 2001). The sum of gas purchases from electric utilities is assumed to equal the total global emissions of SF<sub>6</sub> from electrical equipment.

#### ***Global SF<sub>6</sub> Emission Apportionment***

EPA assumed that SF<sub>6</sub> emissions are proportional to electricity consumption. Emissions of SF<sub>6</sub> are allocated to each country based on their share of total world electricity consumption.

Exhibit D-6 presents SF<sub>6</sub> emissions estimates from electric utilities.

### **5.4.6 Emissions from Semiconductor Production**

Estimates for Canada, Japan, and the U.S. are taken from country submitted reports (Environment Canada 1997; METI, 2001; and EPA, 2001b, c). For the remaining countries, the following methodology was used to estimate emissions of high GWP gases (PFCs) from the semiconductor industry.

1. **Analytical Approach:** Throughout this analysis, EPA assumed that emissions from semiconductor manufacturing are proportional to MSI-Si layers processed<sup>6</sup> (and to MSI-Si layer processing capacity) in the world and in each country. In its analyses of the U.S. industry, EPA has found that emissions are closely correlated with MSI-Si layers processed.
2. **Global Emissions:** To develop estimates of global emissions from 1990 through 2010, EPA began with estimates of U.S. emissions for 1990

through 2010. These U.S. estimates have been developed based on emissions information supplied by participants in EPA's PFC Reduction/Climate Partnership with the semiconductor industry, and on estimates of MSI-Si layers processed in the U.S. To scale up these estimates to the global level, EPA estimated the share of world MSI-Si layer capacity accounted for by the U.S. World and U.S. MSI-Si layer capacity were estimated using SEMI's 2001 Fabs on Disk database for the linewidth technologies in place in 2000. The International Technology Road map (SEMATECH, 2000) provided the number of layers associated with each linewidth technology. EPA then divided the emissions projections for the U.S. by the U.S. share of MSI-Si layers to obtain emissions projections for the world.

3. **Country-Specific Apportionment:** EPA used the sources cited above to develop country-by-country estimates of MSI-Si layer capacity. EPA then multiplied the emissions projections for the world by the country-specific shares of world MSI-Si layers to obtain the country-by-country emissions estimates.

Emissions from semiconductor production are presented in Exhibit D-7.

## 5.5 Explanatory Notes

1. The Corinair method is an emissions inventory methodology developed by the European Union. A description of the methodology can be found at the following website:  
  
<http://www.ptl-ae.atmoterm.pl/index.html>
2. Norway's National Communication provided an emission estimate for 1990 and 1995; however the 1995 estimate was projected from earlier estimates based on results of "significant" efforts by the magnesium industry to reduce SF<sub>6</sub> emissions. To be consistent with "business as

usual," only the 1990 estimate was used. Estimates for the years 1991-1994 were interpolated to the 1995 value that resulted from this analysis. Estimates for 1995 forward were consistent with the methodology outlined in this chapter.

3. In 1990, the European Economic Community (EEC) included 12 nations: Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, and United Kingdom. The EEC is now called the European Union (EU). The EU currently has 15 members, the 12 from the EEC plus Austria, Finland, and Sweden.
4. Ozone depletion potentials (ODPs) are used to quantify the relative damage done to the ozone layer by different compounds. By definition, CFC-11 is assigned an ODP of 1. The use of ODPs, with CFC-11 assigned the value 1, is similar to the use of global warming potentials (GWP) to quantify the relative impact of compounds on radiative forcing, with carbon dioxide assigned a global warming potential of 1.
5. In the UNEP report, the consumption for European Union member nations are aggregated into one EU consumption estimate. In addition, in this analysis the results for the nations that are designated countries with economies in transition (CEIT) are grouped together as one, Australia and New Zealand are reported as one, and the non-EU European countries are reported together as one.
6. MSI-Si layers processed refers to millions of square inches of silicon processed times the number of interconnect layers contained in the semiconductors produced.